arpa·e
CHANGING WHAT'S POSSIBLE

Molten-Salt Methane Pyrolysis Optimization Through in-situ Carbon Characterization and Reactor Design

Fabrication & demonstration of a high temperature, high pressure molten salt methane pyrolysis reactor.

Total project cost:	$2.3M
Length	24 mo.

H2@Scale
U.S. Department of Energy

Binary Chloride Salts as Catalysts for Methane to Hydrogen and Graphitic Powder

Production and continuous removal of graphitic powder from a molten salt methane pyrolysis reactor.

Total project cost:	$1.2M
Length	24 mo.

Fadl Saadi, C-Zero
Director of Business Development

The Team

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CTO

Zach Jones
CEO

Steve Calderone
VP of Engineering

Arnie Smith
Exec. Dr. Process Engineering

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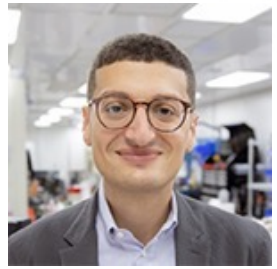
Technical Strategist



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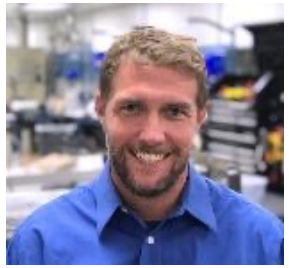

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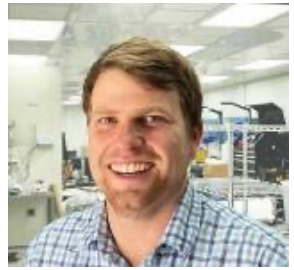
Senior Engineer



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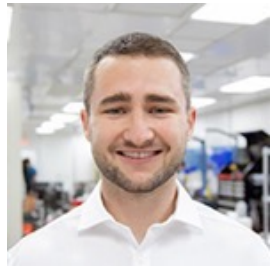
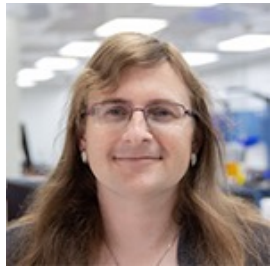
Ryan Patrick
Engineer

Joshua Rodriguez
Engineer

Sydney Bartone
Business Op Associate



Henry Moise
Engineer



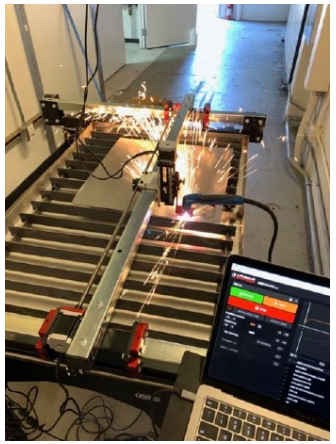
Ashley Carmichael
Lab & HSE Manager

Collaborators

Prof. Mike Gordon
UCSB

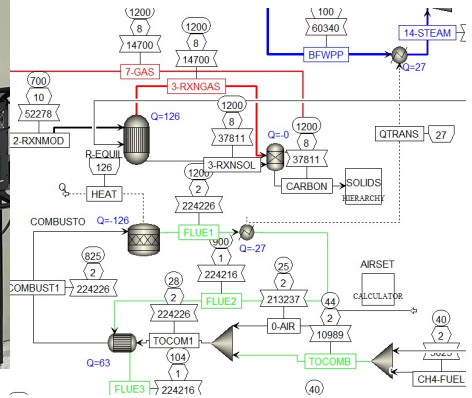
Prof. Raphaele Clement
UCSB

Lab Facilities and Capabilities

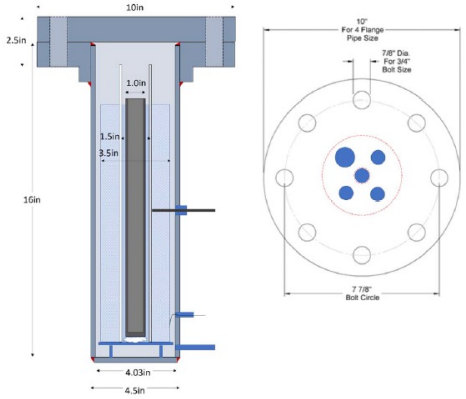


CNC Plasma & TIG Welding

Microscopy, Spectroscopy, Elemental Analysis



Process Modeling



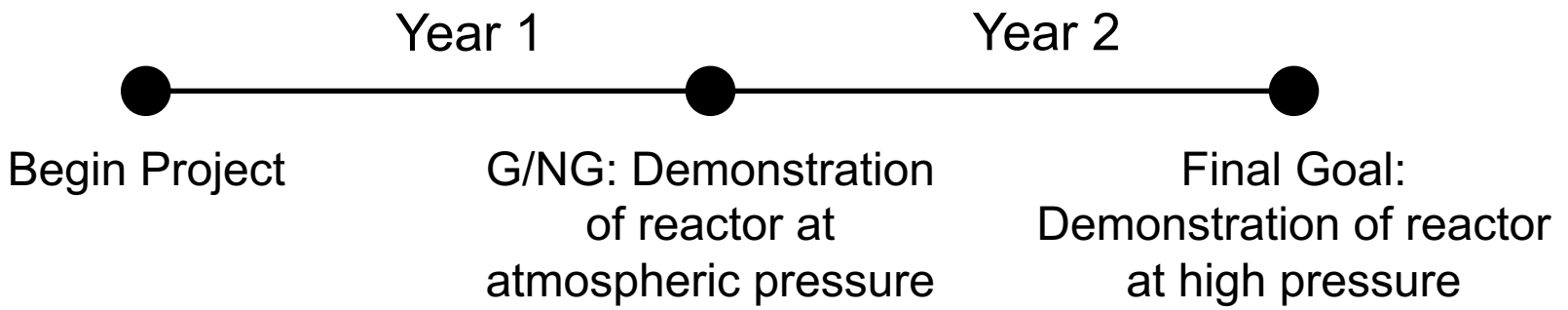
Design & Modeling

C-Zero's investors & partners

Objectives for ARPA-E Project

- Demonstrate in-situ spectroscopic measurements of carbon formation under methane pyrolysis reaction conditions.

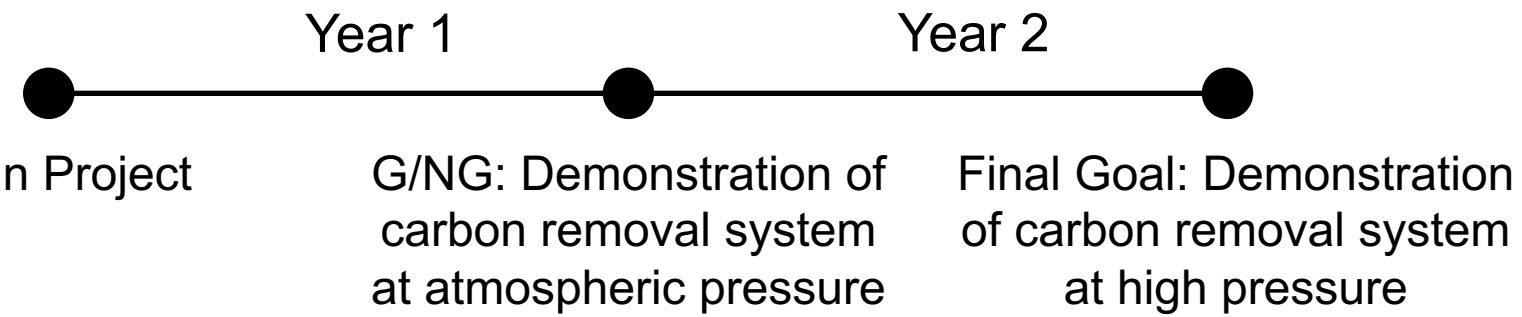
- Design and construct a methane pyrolysis reactor with:
  - ≥ 70% CH_4 conversion
  - ≥ 90% H_2 selectivity
  - ≥ 5 mol H_2/ m^3 s
  - High Pressure (≥ 5 bar)



Objectives for H_2@Scale Project

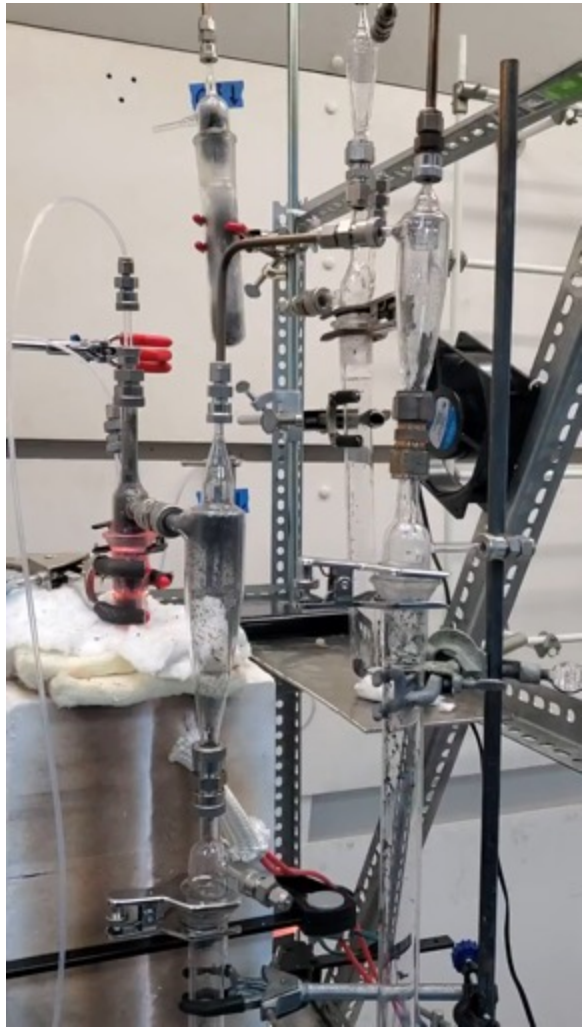
- Demonstration of stable, active, melt system:
  - ≥ 90% H_2 selectivity
  - Graphitic carbon product that has properties favorable for battery anodes and additives

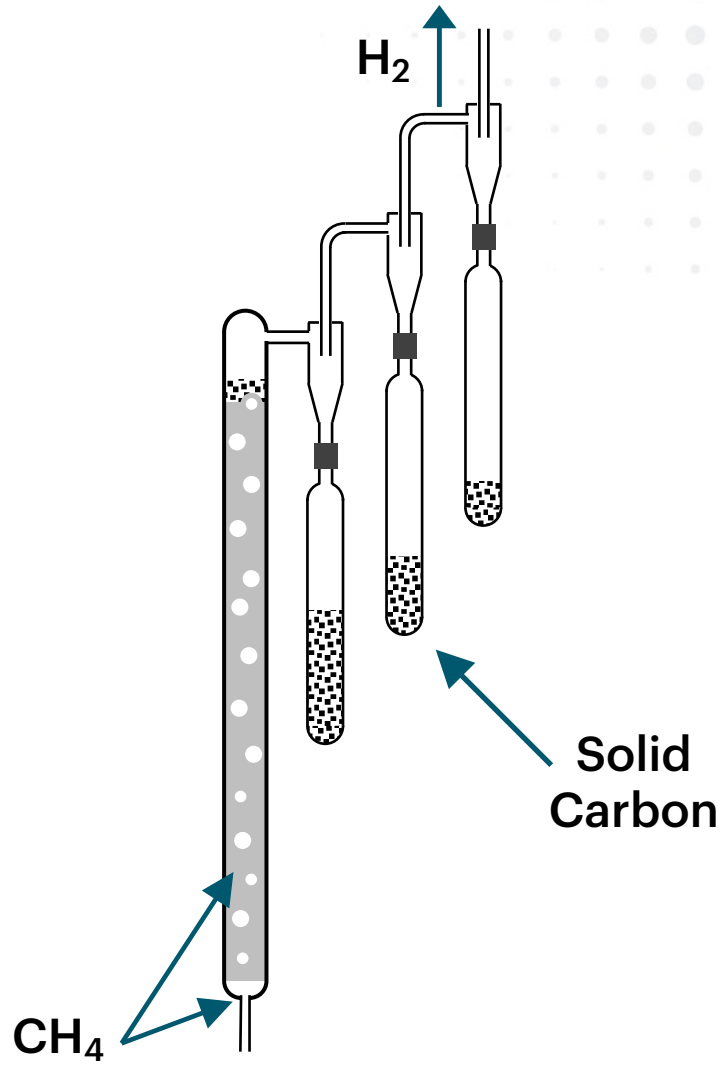
- Design and construct a carbon removal system capable of:
  - High Temperature (1000 C)
  - Continuous carbon removal (≥ 24 hours)
  - High Pressure (≥ 10 bar)



Continuous Carbon Fluidization

- Demonstrated continuous carbon removal from methane pyrolysis via fluidization (>24 hrs)
- 3-phase disengagement zone designed for minimal liquid carryover
- Carbon separation conducted via conventional gas/solid separation methods (cyclones in series)



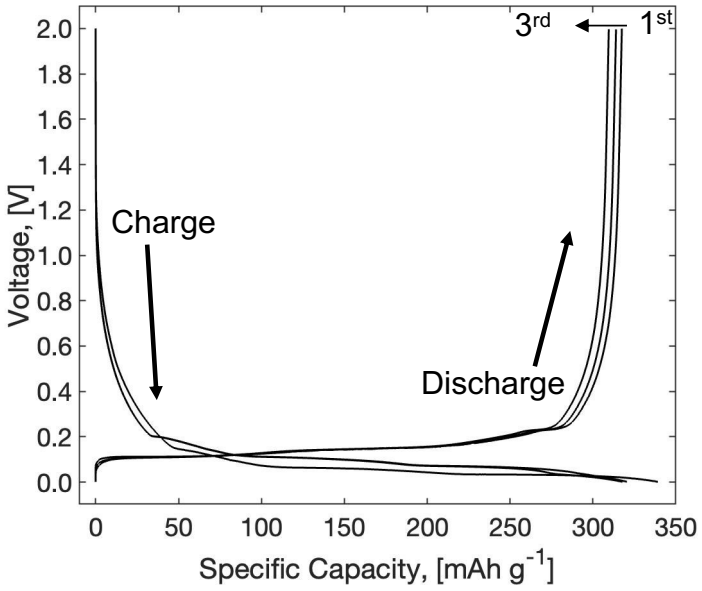


High Pressure Reactor Demonstration

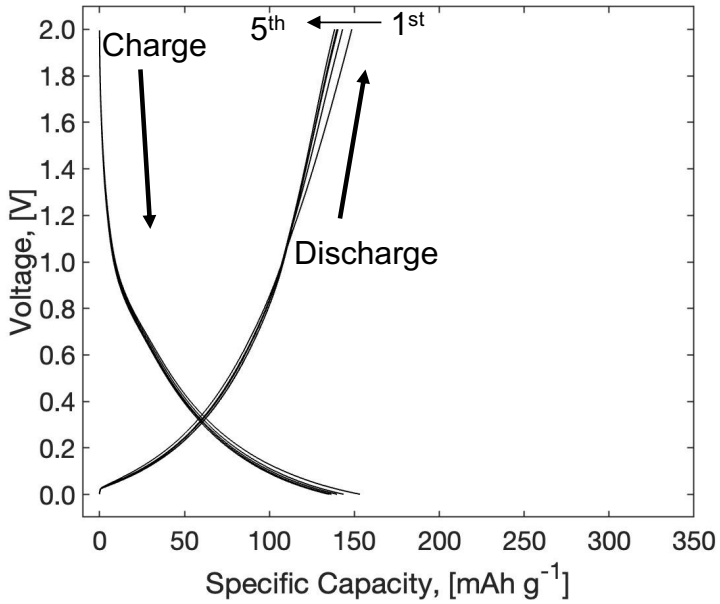
- High pressure (up to 20 bar) methane pyrolysis demonstrated with continuous carbon removal using internally heated reactors
- Stainless steel cyclones fabricated via additive manufacturing
- System successfully operated continuously for >6 hrs

Analysis of Carbon for use in Battery Anodes

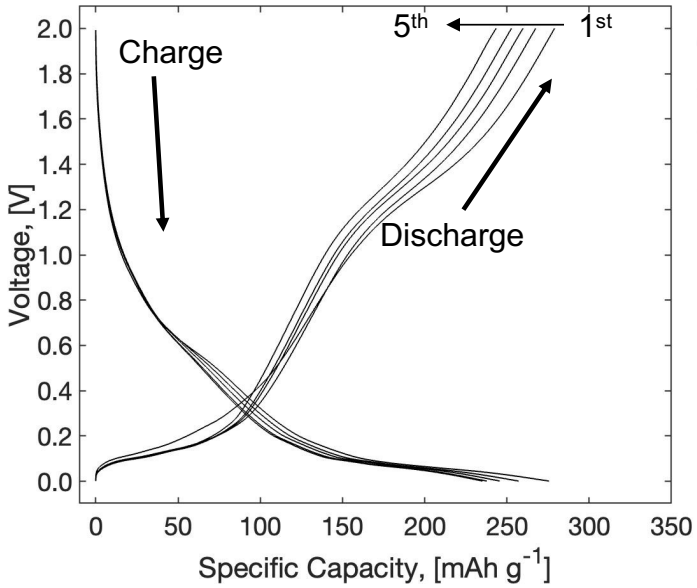
Commercial Graphite



Carbon produced with KCl at 1000 °C



Carbon produced with $MnCl_2$-KCl at 1000 °C



- Several carbon uses in consideration including biochar, activated carbon and battery anodes
- Analyzed carbons from different methane pyrolysis melts for use as li-ion battery anodes
- Showed significant differences between carbons from different melts with some carbon specific capacities approaching commercial grade graphite (~300 mAh/g)

Challenges and Potential Technical Partnerships

- Disruptions due to COVID were inevitable but largely minimized by ensuring strict lab hygiene and proactively purchasing supplies to avert supply chain disruptions
- C-Zero is working with several specialty consultants in different areas (materials of construction, molten systems, reactor design) but always interested in further collaborations especially in the carbon analysis area
- Current primary focus is EPC and site selection for C-Zero's first pilot system
- Interested in collaboration with waste management companies on solid carbon disposal from methane pyrolysis
  - Great opportunity for waste management companies to get in on the clean energy transition- a 'concentrated' form of carbon sequestration

T2M

- C-Zero is developing its first pilot plant with aims to operate by the end of the year
- EPC arm of C-Zero's largest investor, SK, interested in constructing and deploying C-Zero commercial units once the process has been sufficiently de-risked
- C-Zero has signed LOIs with utilities with >100 GW of natural gas electrical generation capacity
  - This would translate to >30 million tons of H_2 or ~3x current US H_2 production
- Rapidly evolving clean energy and hydrogen public policy both domestically and internationally
  - Important to make sure that methane pyrolysis is not 'left out'